IRISH RESEARCH COUNCIL
An Chomhairle um Thaighde in Éirinn

The Solar Wind In Time

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1. Summary

Why study the solar wind evolution?

- Winds directly affect the evolution of stars through the removal of angular momentum and mass.
- Since the winds of solar-like stars are so tenuous we have little information on their mass-loss rates.
- We gain an understanding of the Sun along the main sequence from the past to the future.

How to study the solar wind evolution?

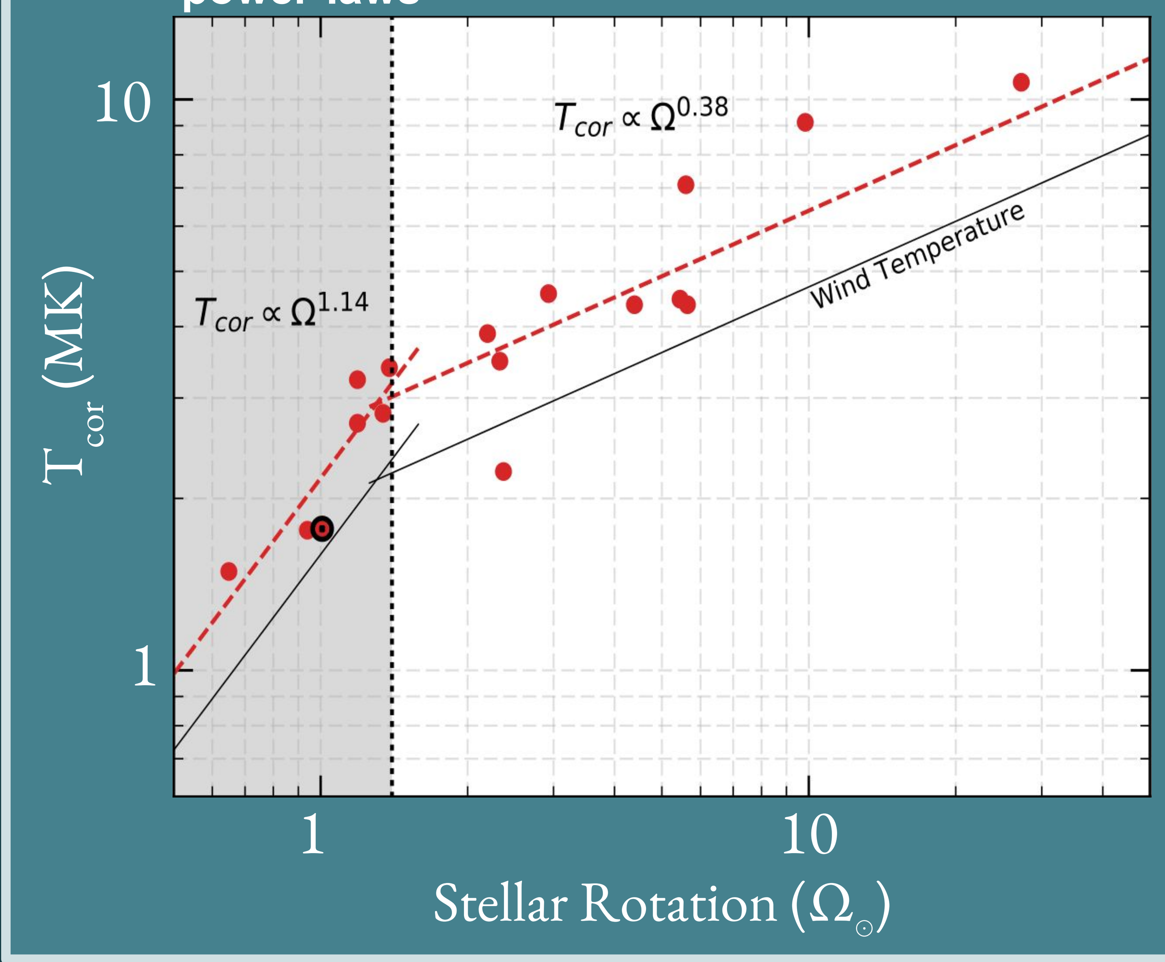
- Our sample consists of Sun in Time objects: rotation rates of 0.7-9.8 $\Omega_\odot$ and ages 0.1-7 Gyr (Guinan et al. 2009).
- Our models:
  - 1D hydrodynamic winds to explore the parameter space (Ó Fionnagáin & Vidotto, 2018).
  - 3D magnetohydrodynamic (MHD) simulations in our current work (Ó Fionnagáin et al., in prep.)

2. Stellar Wind Model

- We use X-ray observations to constrain the wind temperature (Johnstone & Gudel, 2015) and base density by (Ivanova & Taam, 2003):

$$n = n_\odot \, \Omega_\odot^{0.6}$$

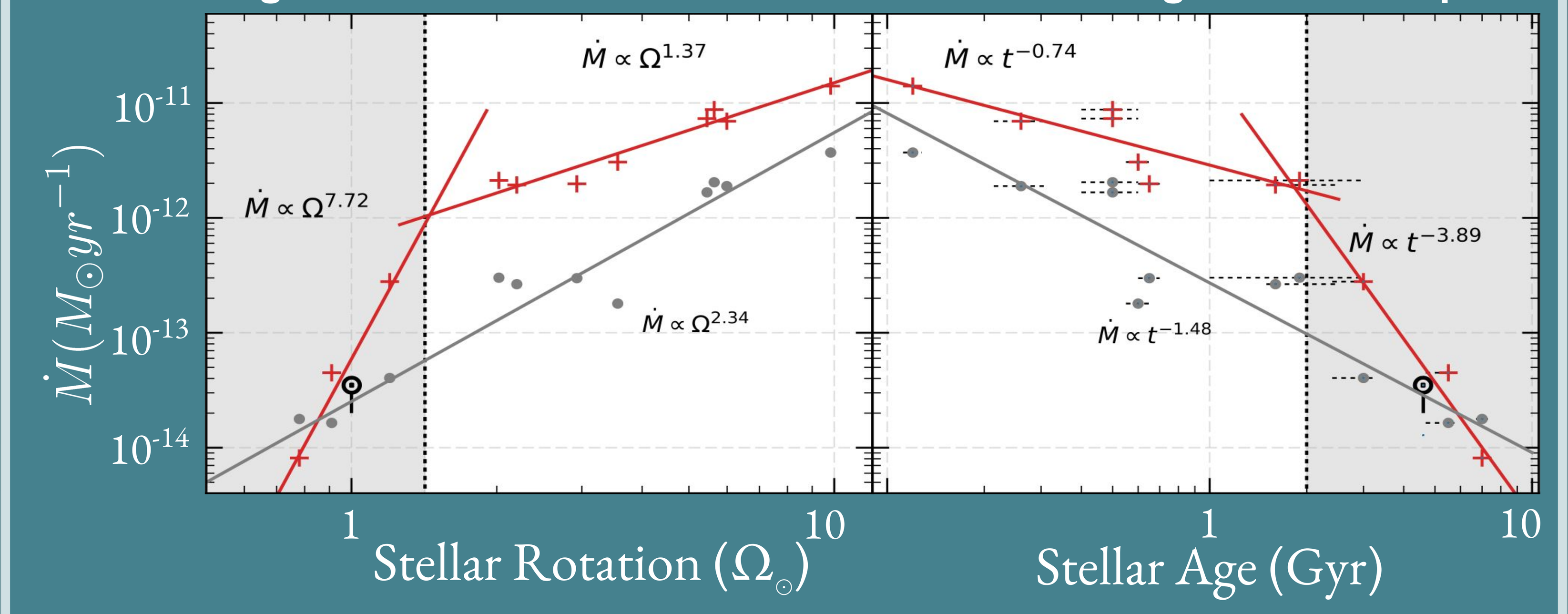
Fig 1: We correlate observed X-ray derived coronal temperatures to rotation with 2 power-laws



3. Wind break at older ages?

- We simulate the winds of solar analogues using a 1D HD thermally accelerated model. (Ó Fionnagáin & Vidotto, 2018).

Fig 2: Mass-loss rates vs. Stellar rotation and age for 1D sample.



- Decreased $\dot{M}$ could explain anomalously rapid rotation in older solar-like stars (Van Saders et al., 2016).

4. Evolution of the Solar Wind

- We focus on Sun in Time objects with magnetic maps from the Bcool collaboration.
- We calculate angular momentum-loss ($\dot{J}$) and mass-loss ($\dot{M}$) rates, and derive the large scale wind topology and magnetic fields.

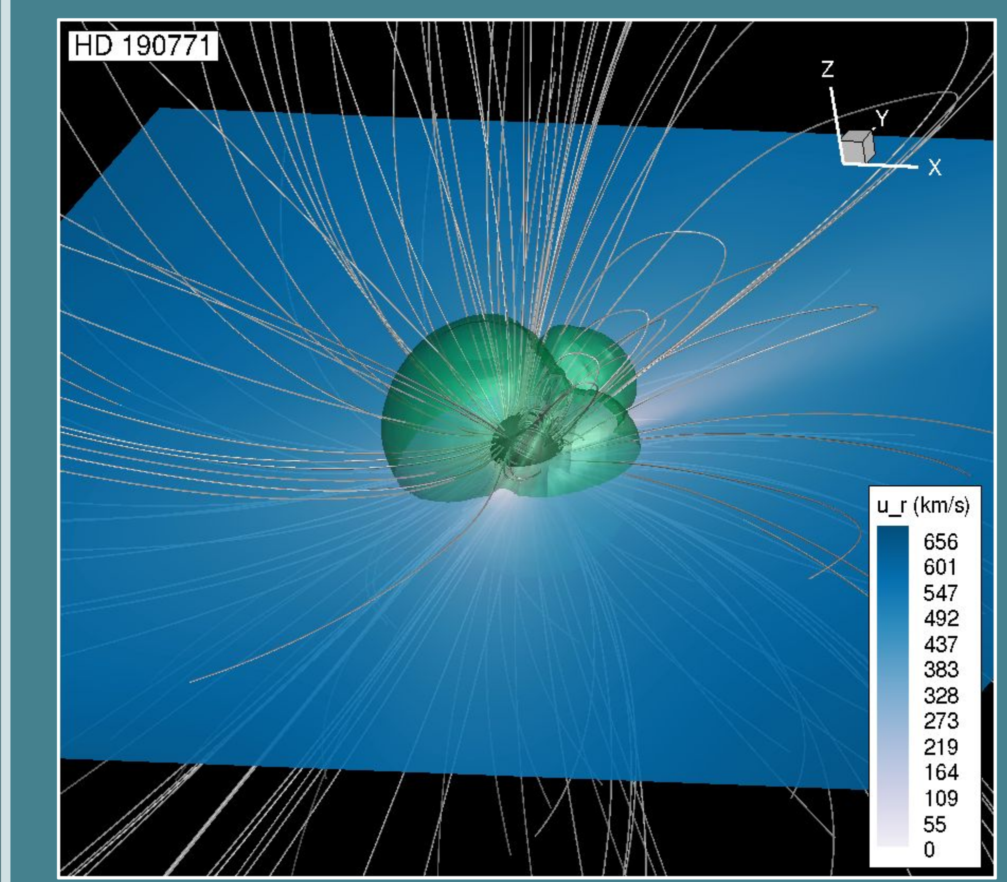


Fig 3: Simulation of HD 190771. Velocity in xy plane (blue) and Alfvèn surface (green).

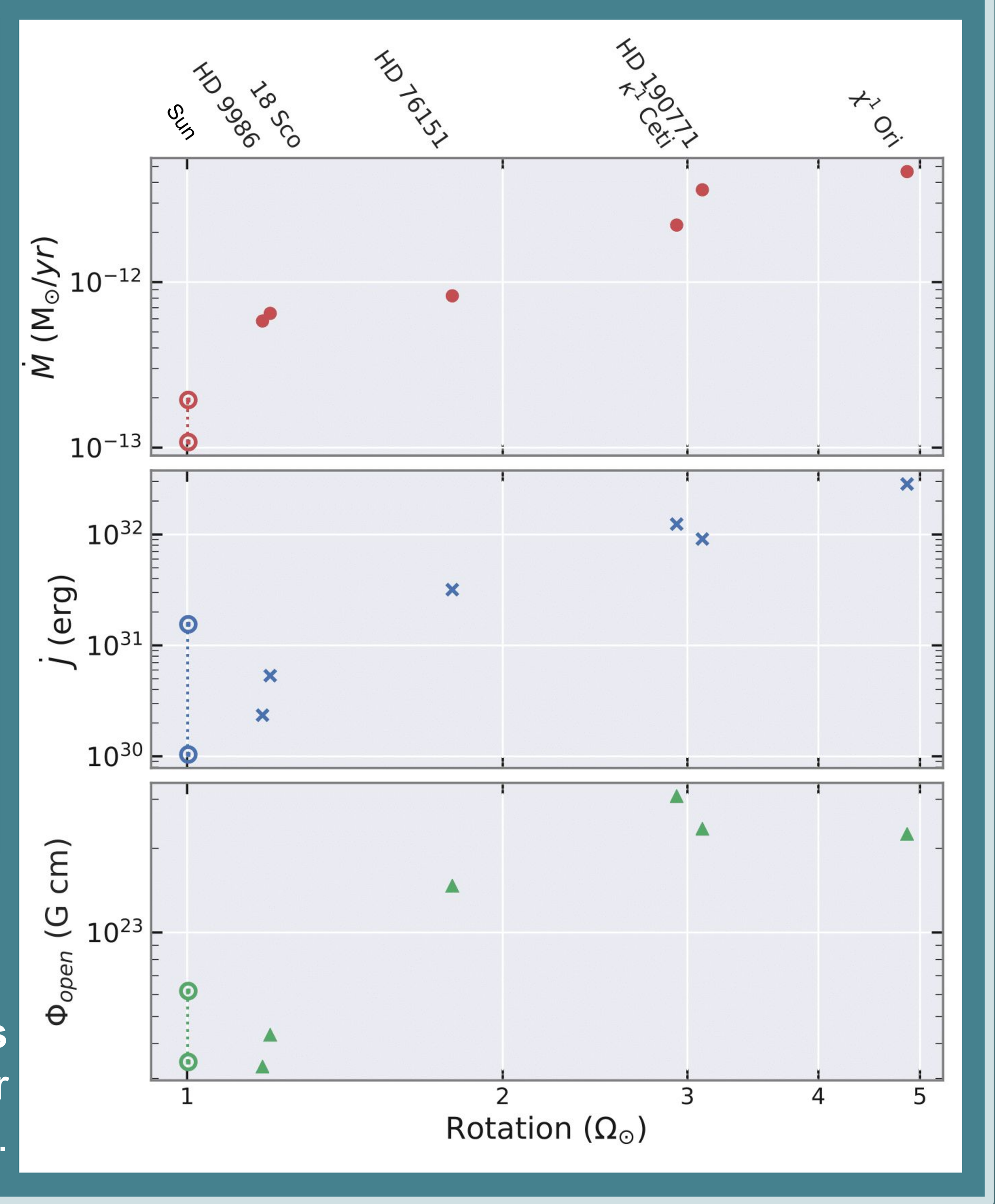


Fig 4: Mass-loss, Angular momentum-loss rates and open flux. We see each parameter decrease with slower rotators.

5. Can we detect solar-like winds in radio?

- We calculate thermal free-free radio emission from the wind of each star.
- Fig. 5 shows the expected radio emission from κ^1 Ceti at 100 MHz. Contours show the radio photosphere of the wind.
- Fig. 6 shows the radio spectrum for our 3D sample of stars.

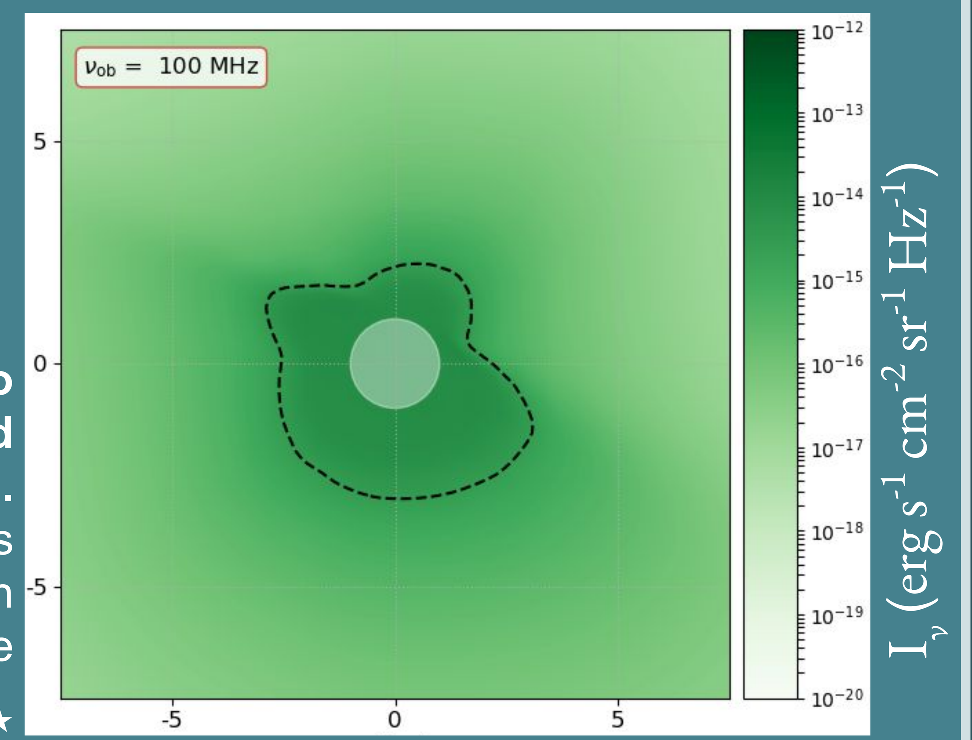


Fig. 5: Anisotropic radio emission from the wind of κ^1 Ceti. Inside contours wind is optically thick. Observation frequency is 100 MHz. The white circle denotes 1 $R_\star$

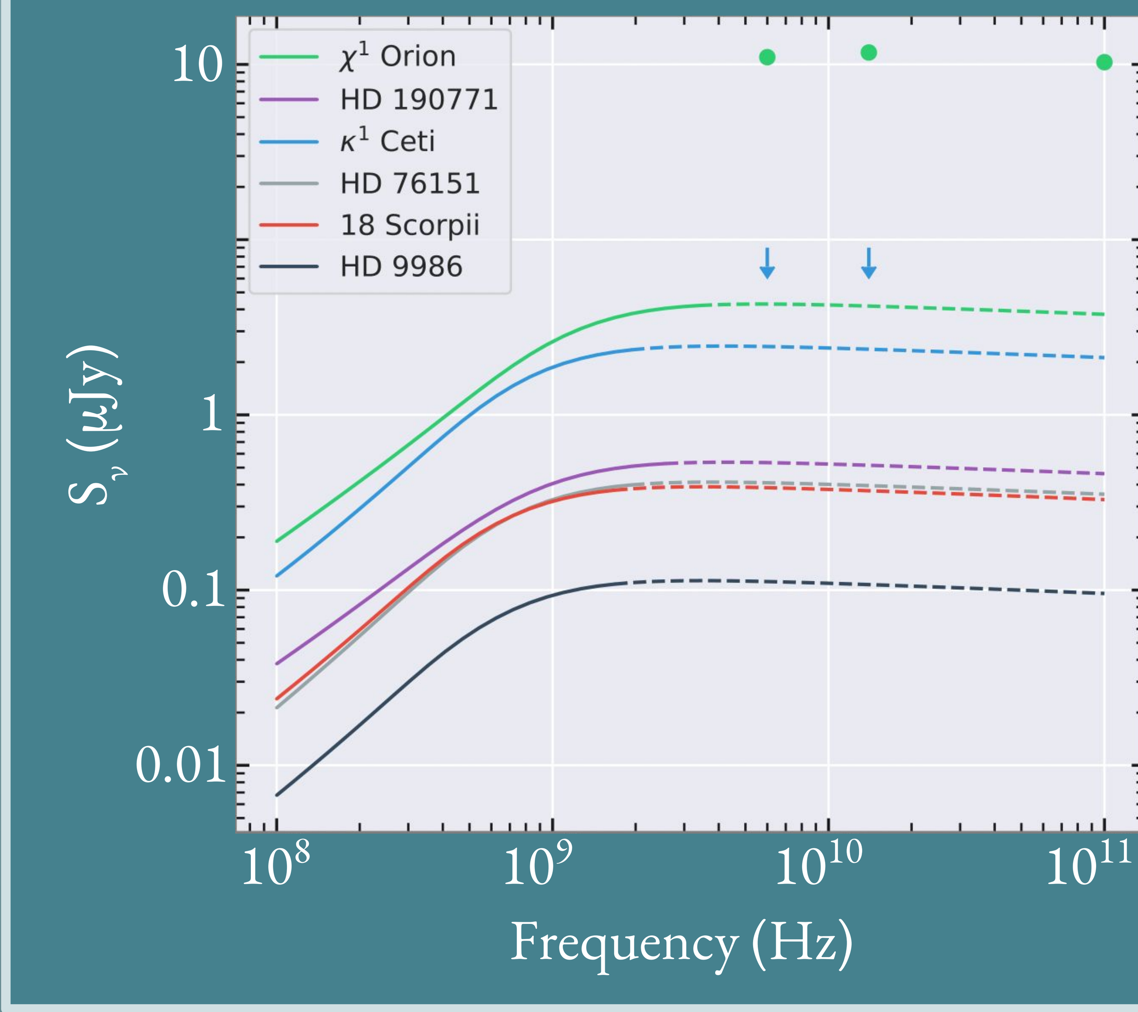


Fig. 6 Radio spectra of our 3D simulations: Stellar distances have the largest effect on flux density. Spectrum shape is in general similar across all stars. Dashed lines represent optically thin winds. Observations (dots) and upper-limits (arrows) from Fichtinger et al., (2016).

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- Ó Fionnagáin, D., Vidotto, A. A. (2018), MNRAS, 476, 2465
- Ó Fionnagáin, D., Vidotto, A. A,, Jeffers. S. V., Marsden, S., Morin, J., Petit, P., (in prep.)

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